Neutrinos and the Lyman-alpha forest

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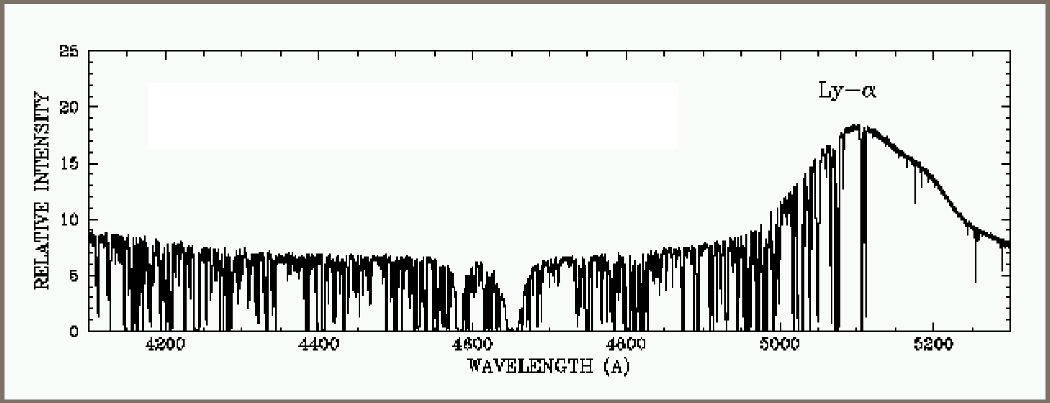


Plan

-The Lyman-alpha forest

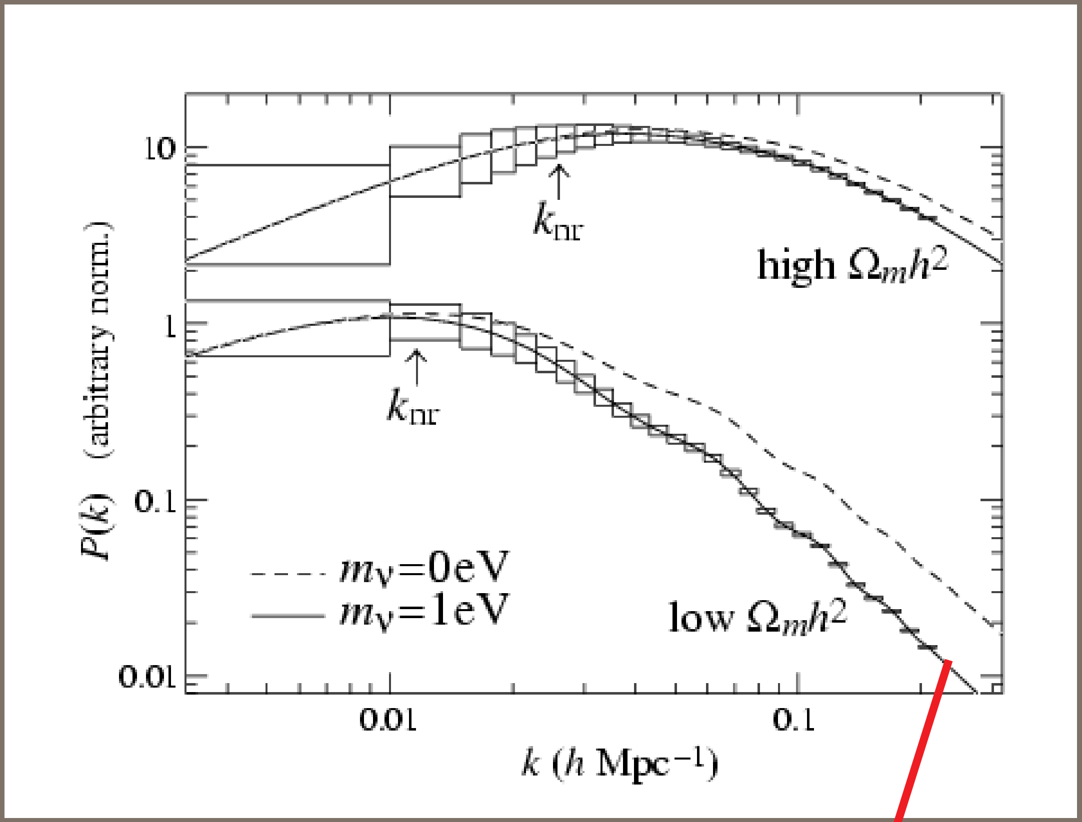
-How to use it to measure clustering of the mass

-Potential changes to the simple picture
  - -galactic winds
  - -radiation fluctuations

- Constraints on the neutrino mass derived from the Lyman alpha forest in 53 Keck spectra.

Neutrinos suppress power spectrum of mass fluctuations on small scales.

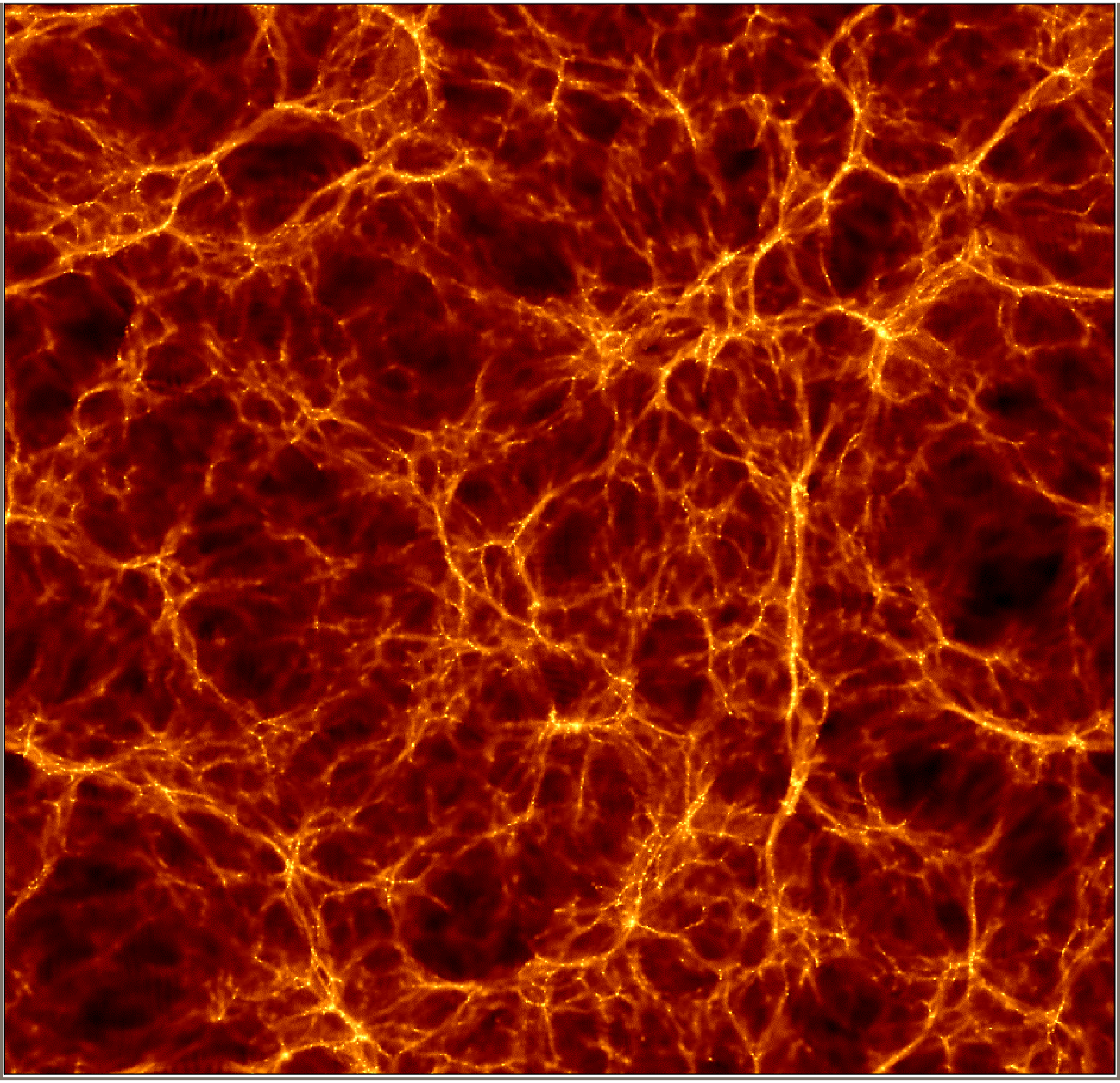
Hu, Eisenstein and Tegmark (1998)



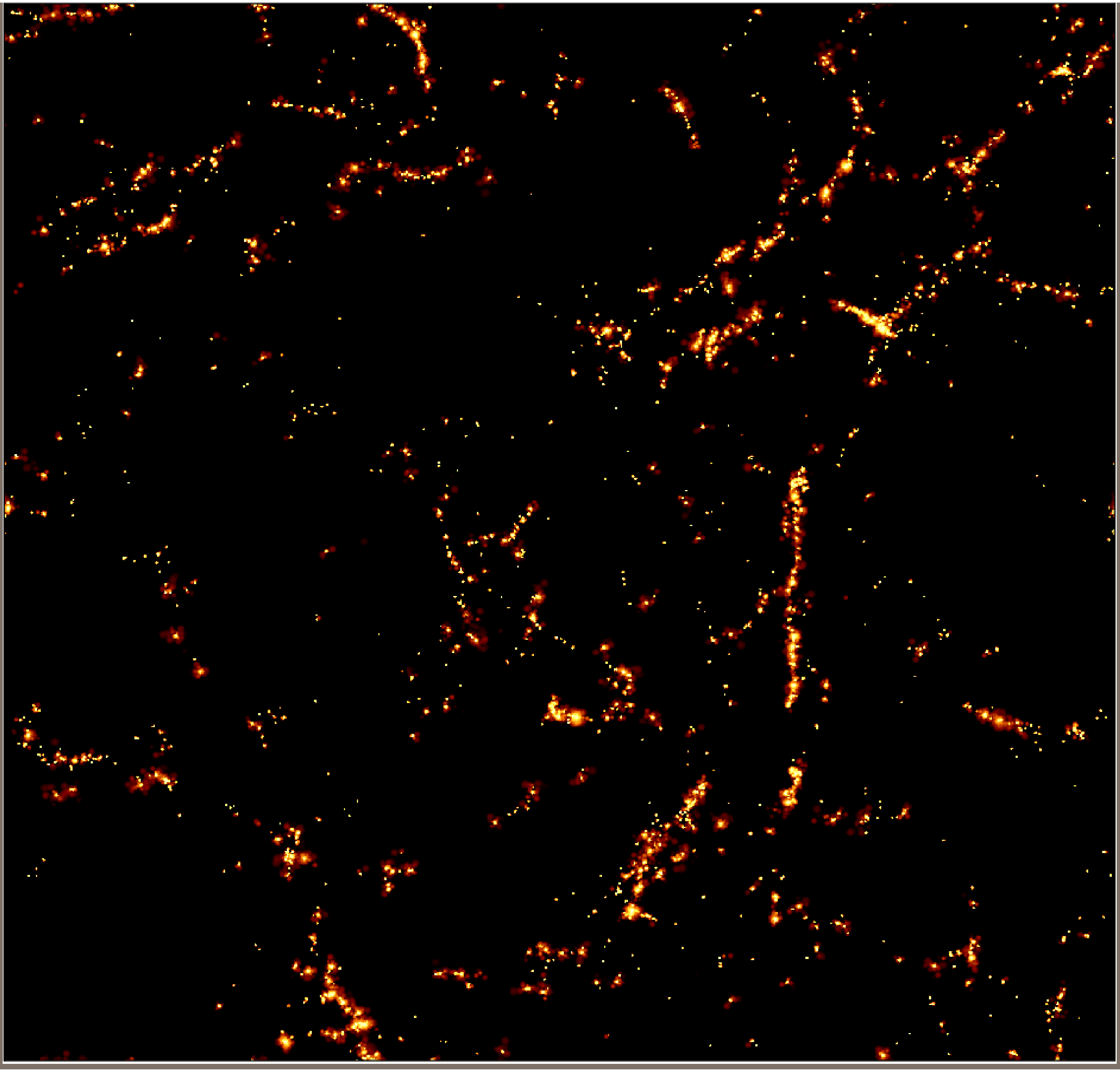
We would like to measure linear clustering on as small a scale as possible

Small scale structure in the IGM distribution at z=3

(33 Mpc/h box)

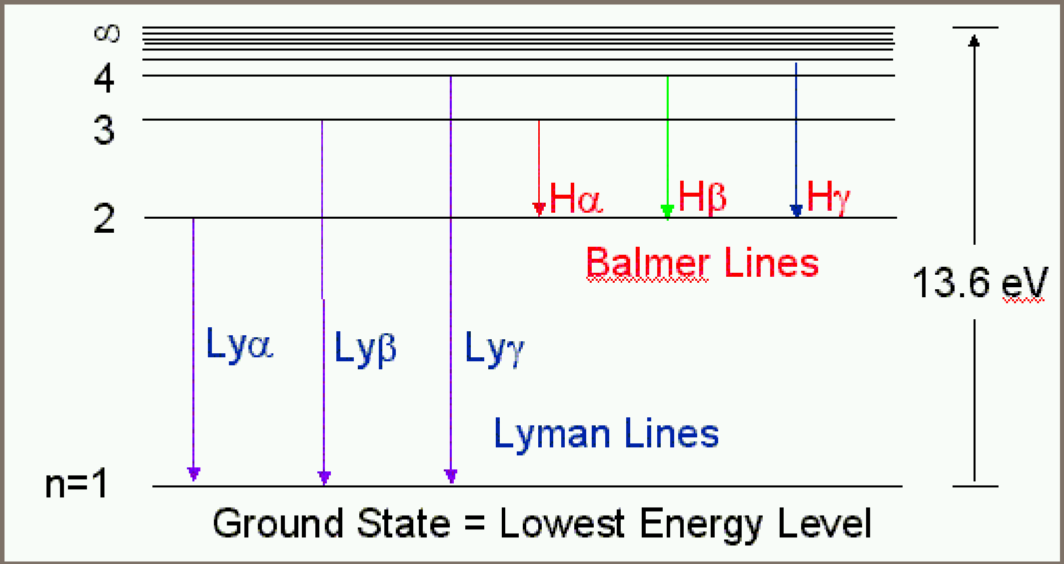


Star formation at z=3 in the same volume



" The atomic transition which is most useful for finding material in absorption is the Lyman-alpha transition of neutral hydrogen.

The energy levels of the Hydrogen atom

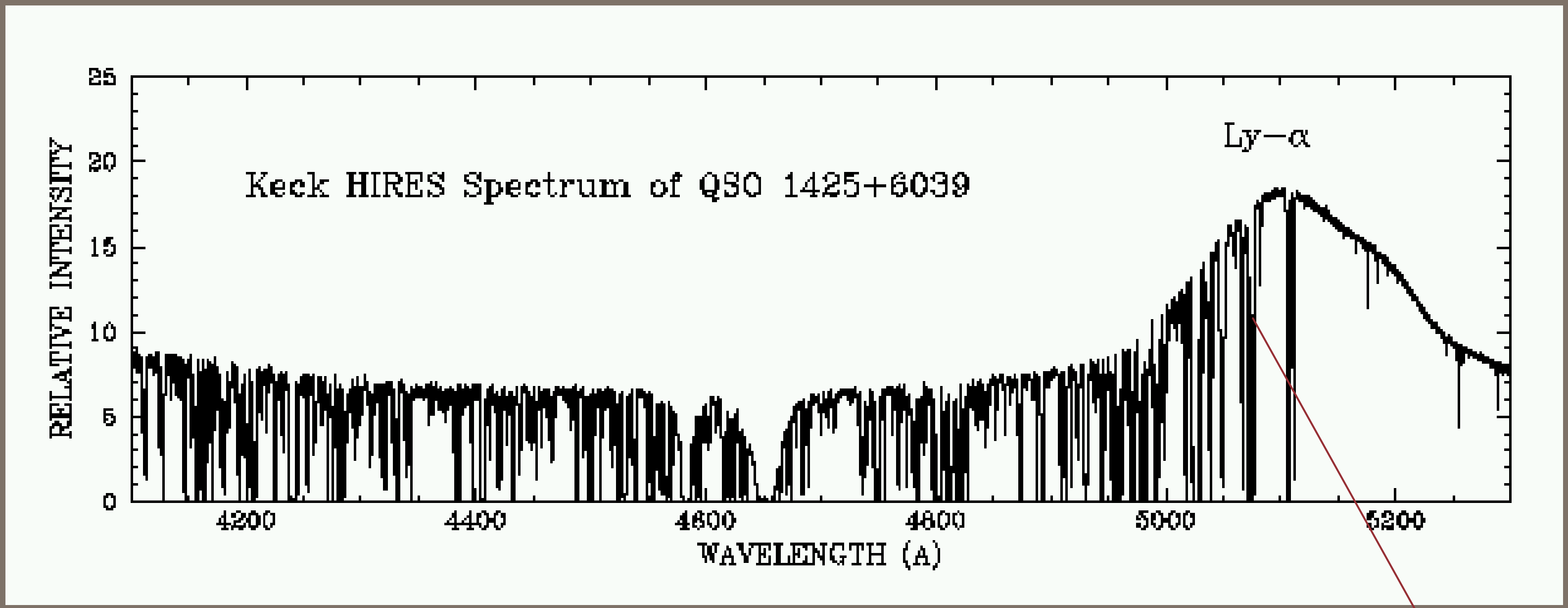


" This is the transition from the 1s to the 2p level.

" An atom in the ground state which absorbs a photon with the correct energy will move to the excited state.

-for Lyman-alpha, the photon with this energy has a wavelength of 1216 Angstroms.

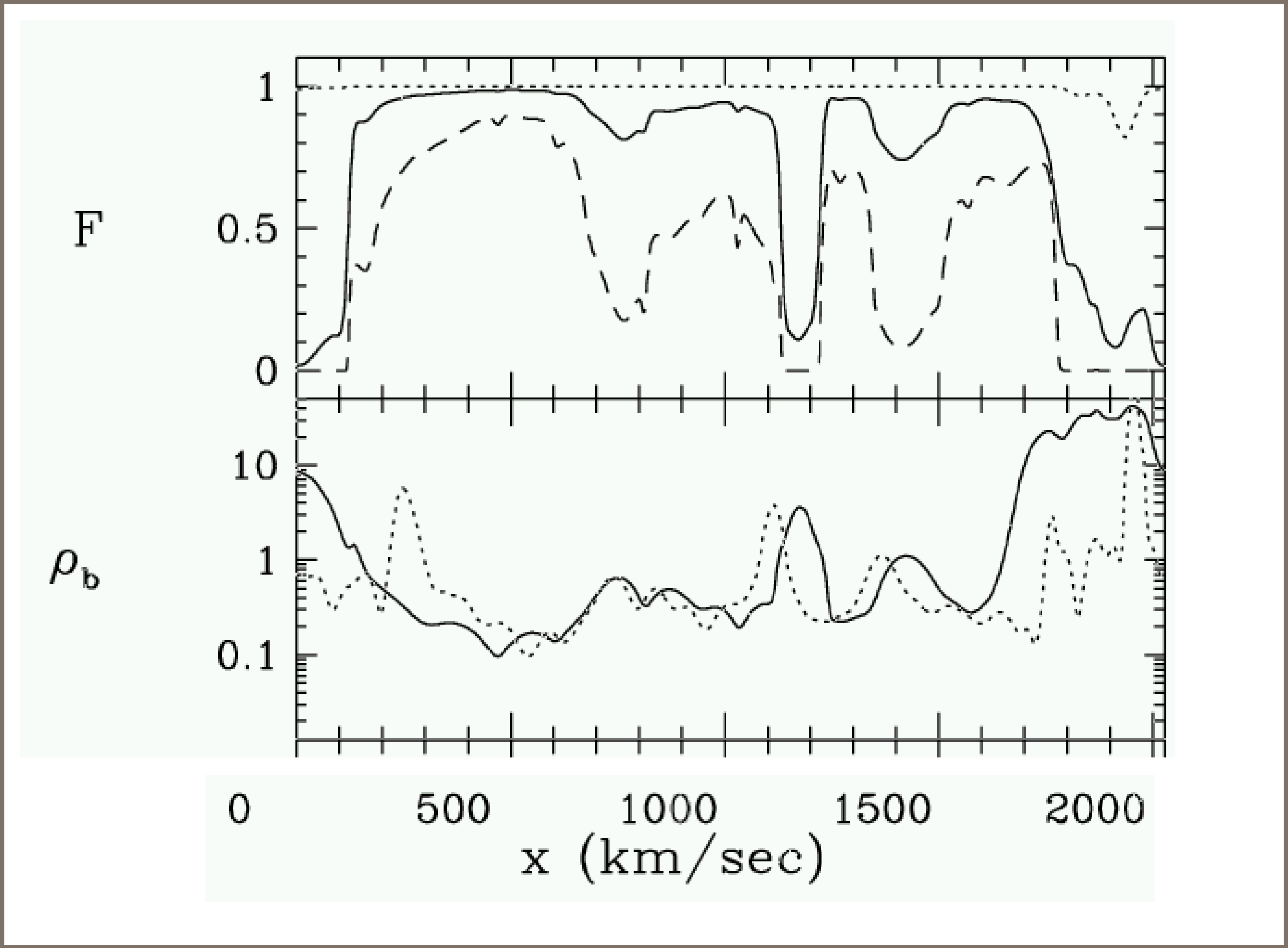
- If we take a spectrum of a quasar, we can see material in absorption:



- Light travelling to us from the quasar gets redshifted by the expansion. When the wavelength of light gets to the Lyman-alpha wavelength, there is a probability that a photon will be absorbed by neutral hydrogen gas at that redshift.

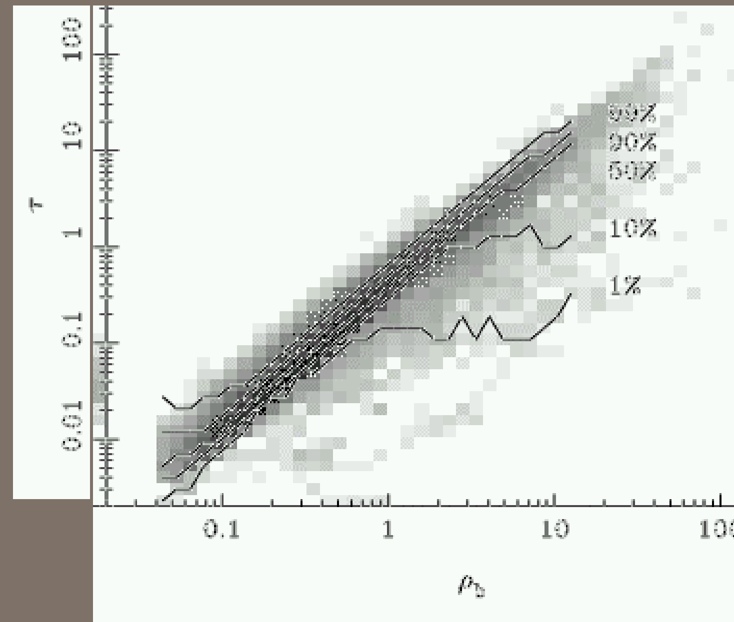
Ly-alpha emission line at quasar redshift

$F = e^{-\tau}$



The Lyman-alpha forest can give us a 1D map of the density field

$$F=e^{-\tau}$$



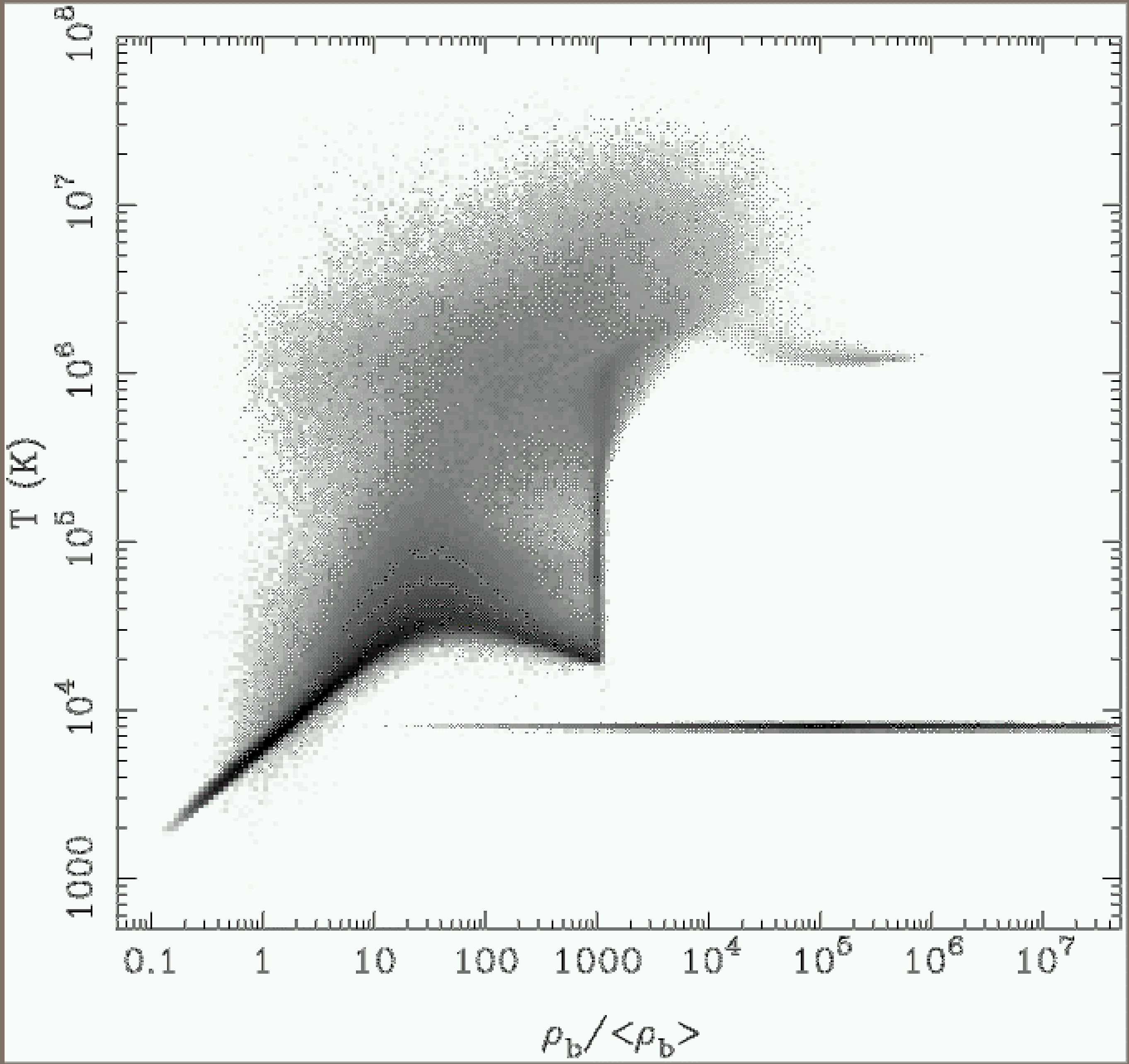
$$\tau \propto n_{HI} = A\,\rho^{\beta},$$

$$A = 0.946\left(\frac{1+z}{4}\right)^{6}\left(\frac{\Omega_b h^2}{0.0125}\right)^{2}\left(\frac{T_0}{10^4\ \mathrm{K}}\right)^{-0.7}\left(\frac{\Gamma}{10^{-12}\ \mathrm{s}^{-1}}\right)^{-1}\left(\frac{H(z)}{100\ \mathrm{km\ s^{-1}\ Mpc^{-1}}}\right)^{-1}$$

$$\Gamma_{\mathrm{H\,I}} = \int_{\nu_{\mathrm{H\,I}}}^{\infty} d\nu\,\frac{4\pi J(\nu)}{h\nu}\,\sigma_{\mathrm{H\,I}}(\nu)$$

We rely on A not fluctuating spatially, so that measuring properties of F will give us properties of ρ (such as P(k))

Temperature of baryons



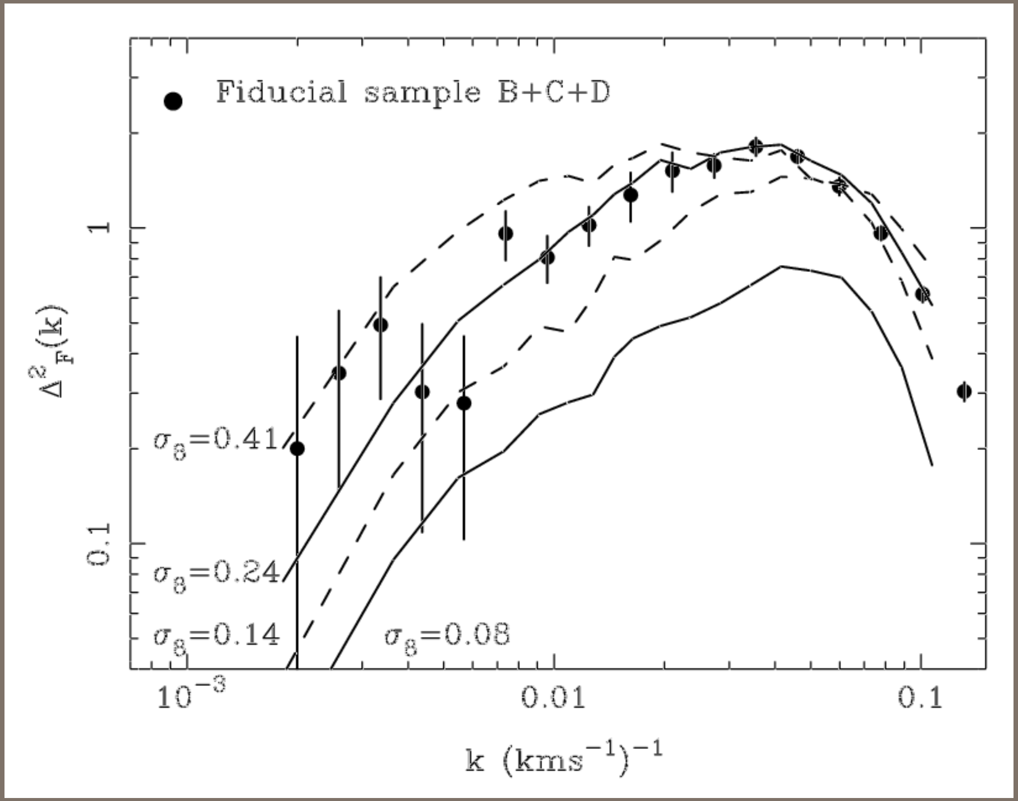
Density of baryons in units of the mean.

$$P_{F,1D}(k) = \langle \delta^2(k) \rangle$$

$$\delta(k) = \frac{1}{2\pi} \int \delta(x) \mathrm{e}^{-\mathrm{i}kx} \mathrm{d}x$$

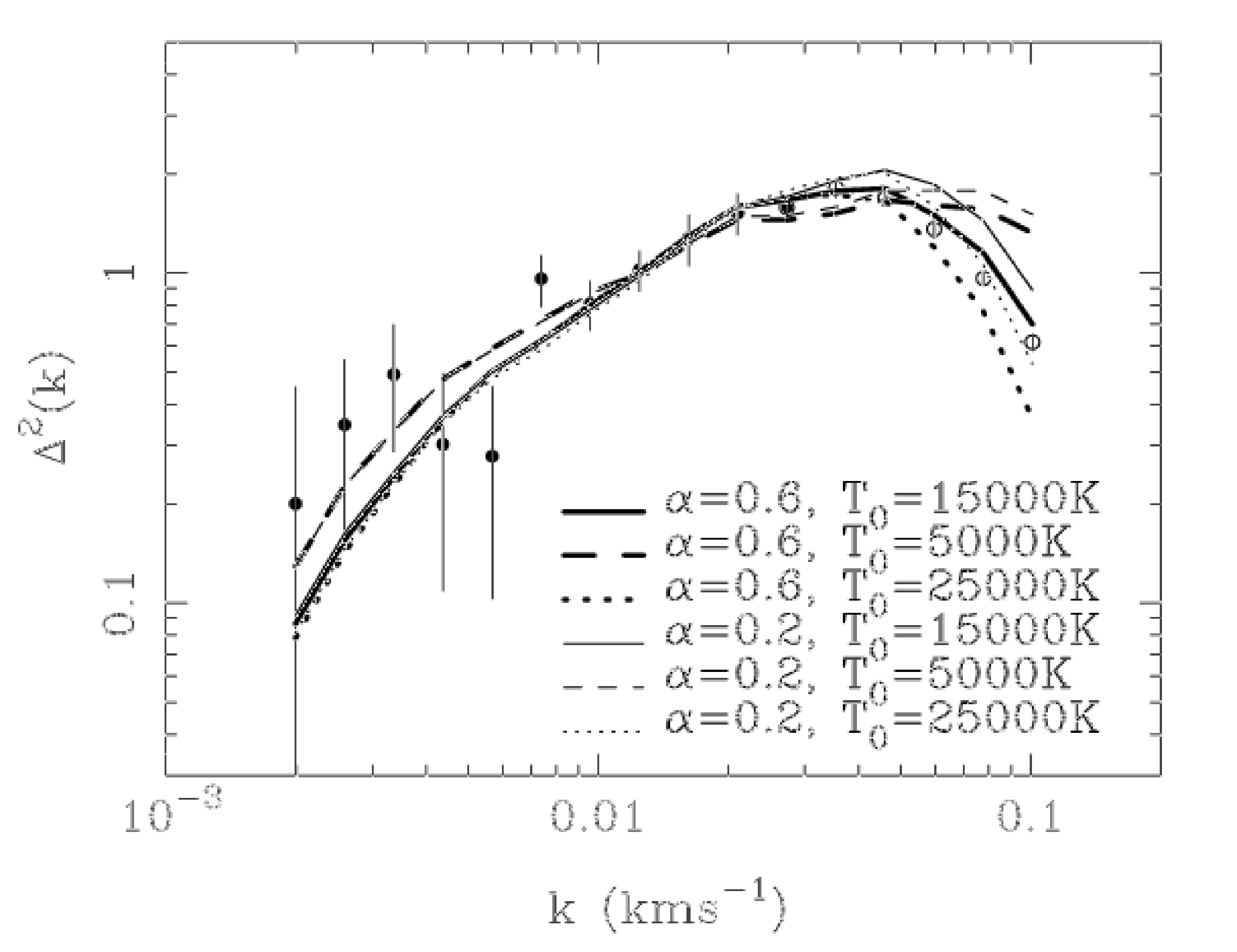
$$\Delta^2_{\mathrm{F}}(k) = -\frac{1}{\pi} k^2 \frac{d}{dk} P_{F,1D}(k)$$

We measure power spectrum of quasar flux and convert to mass power spectum using calibrating simulations.

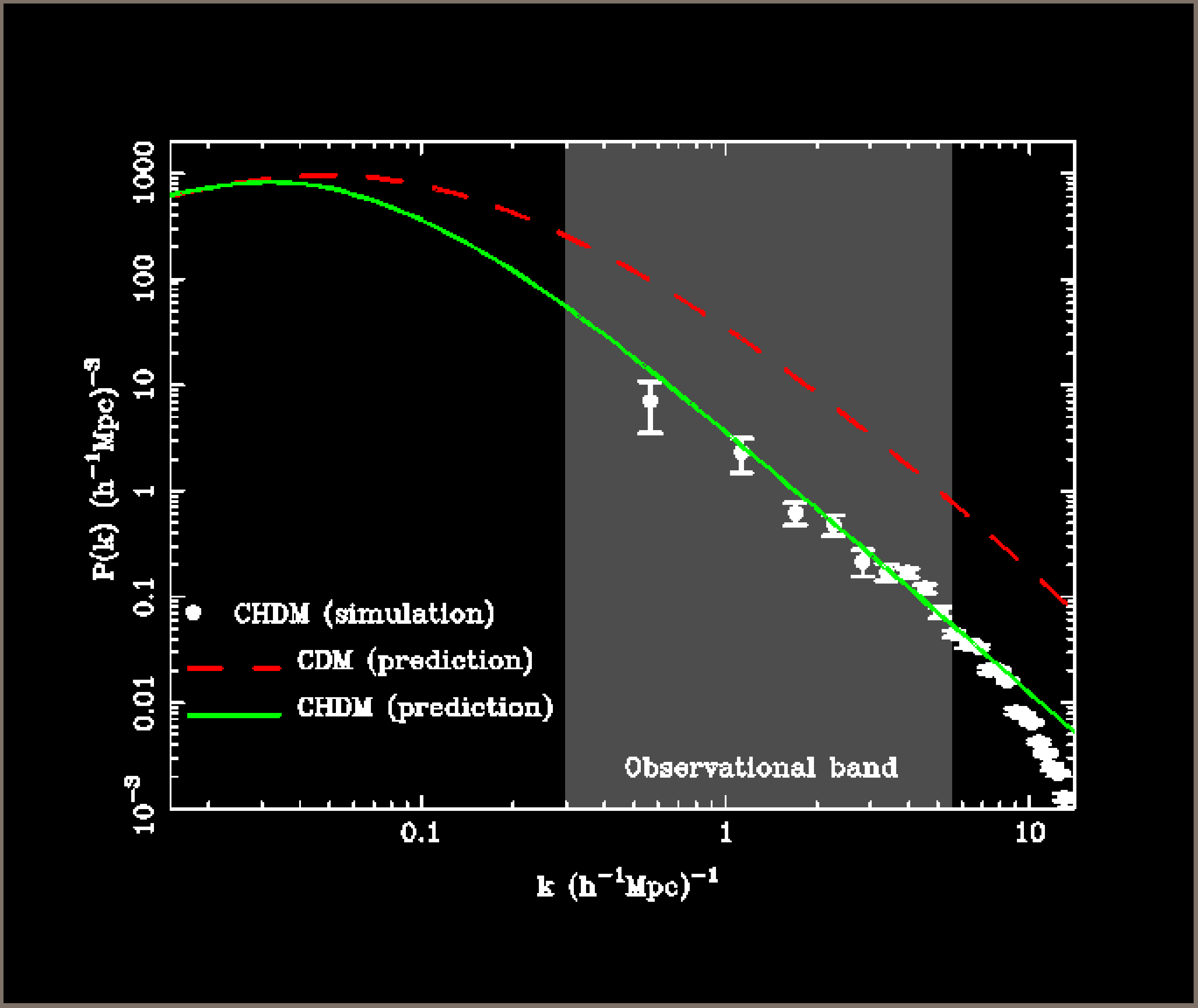


The temperature of the IGM influences the turnover in the power spectrum on scales comparable to the thermal width of lines.

- we exclude data on the smallest scales.



Test of the procedure on a simulated universe which contains “hot” particles with total mass 5eV.

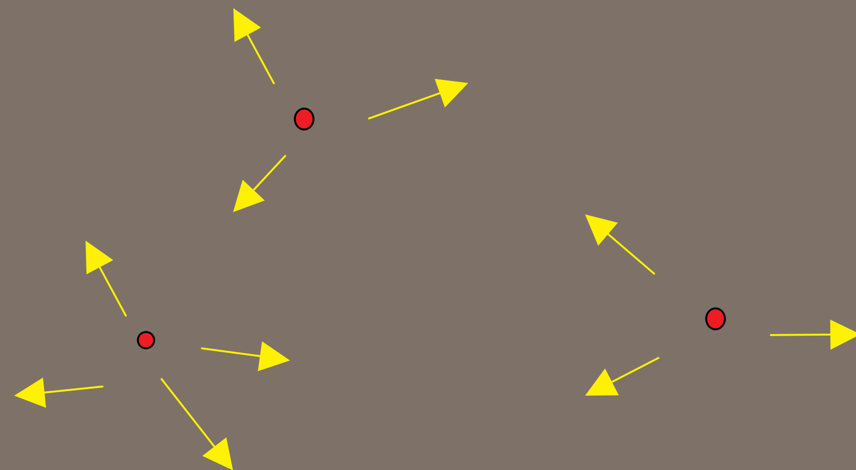


Our current models of the IGM can reproduce many observations. However, they ignore the possible effect of

galactic winds

and

the discrete nature of photoionizing sources (the radiation field is not uniform.)



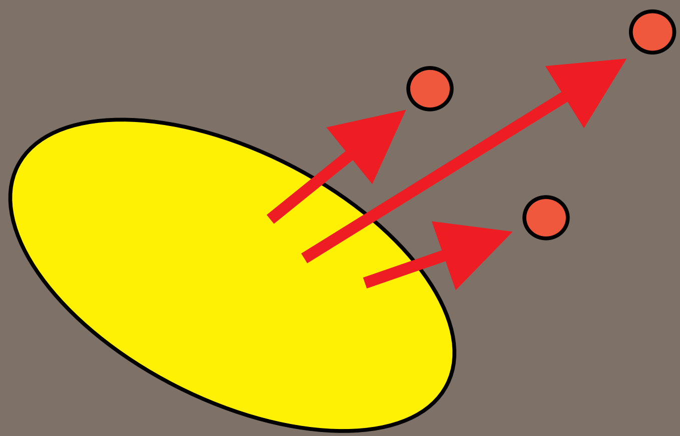
New simulations (Springel et al 2002) include addition of kinetic energy to gas close to

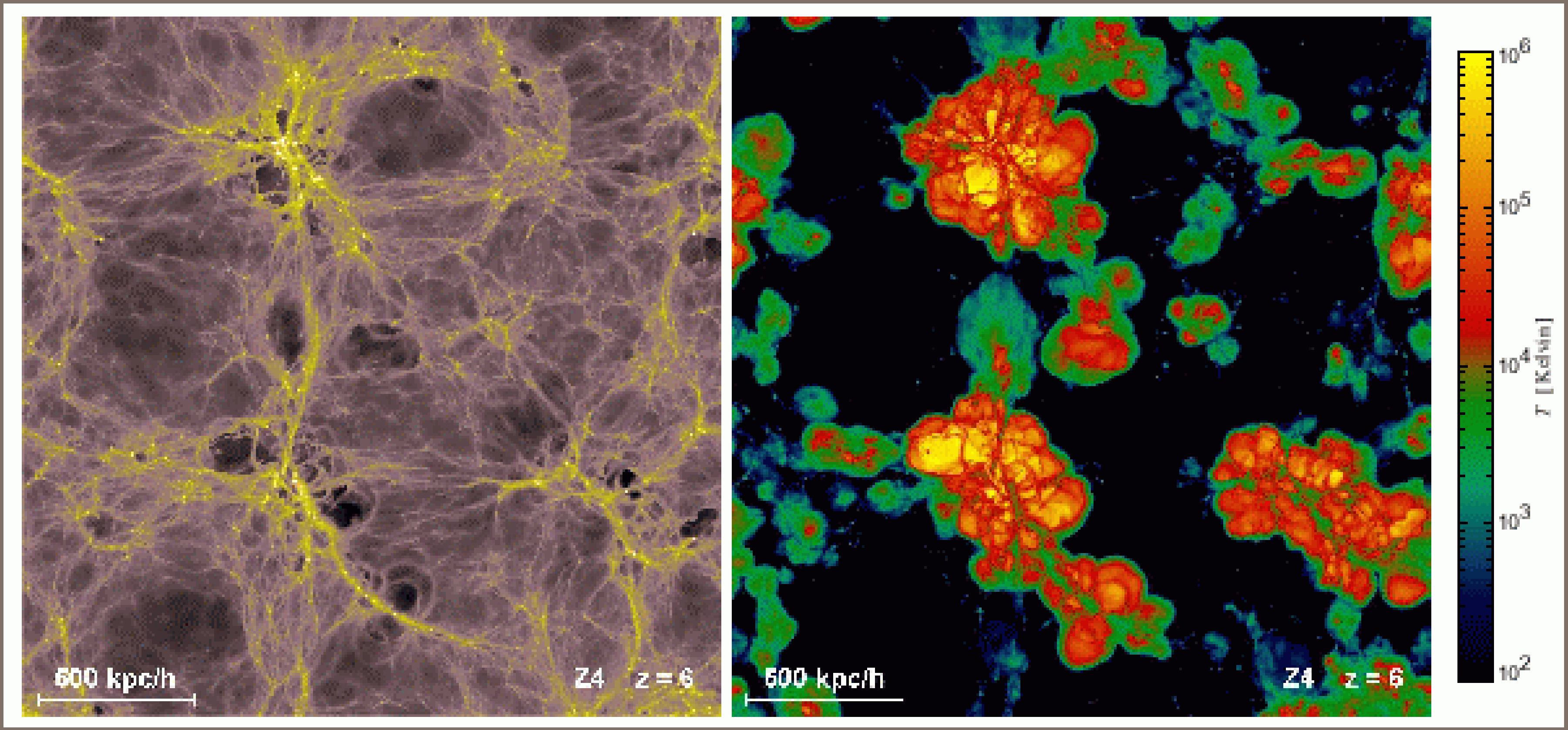
SN in galaxies: creates “wind particles”.

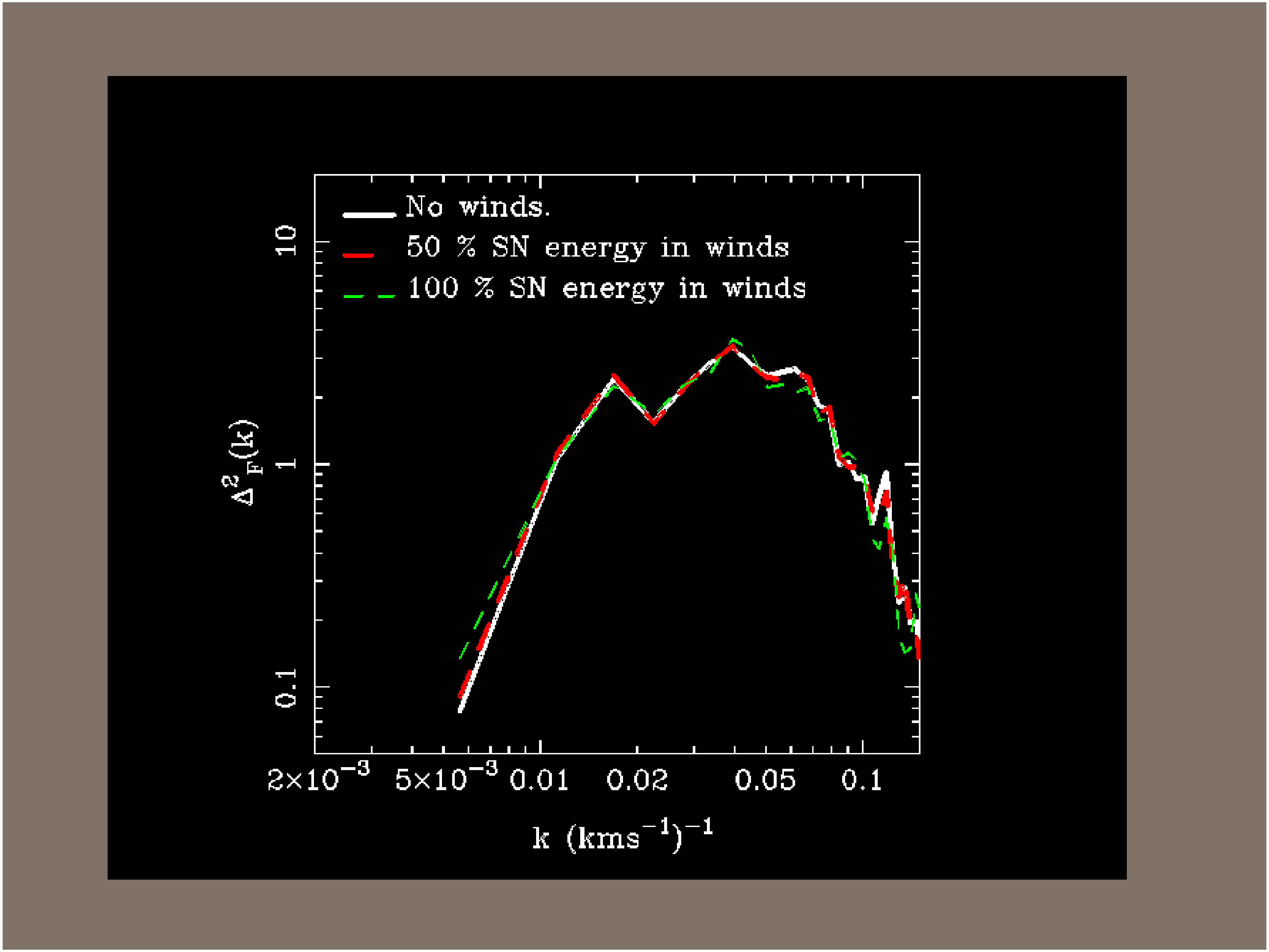
-these can spread metals into the Lyman-alpha

forest to the degree observed.

- what is their effect on the clustering?






No winds.
50 % SN energy in winds
100 % SN energy in winds
$\Delta^2_F(k)$
10
1
0.1
2×10^{-3}
5×10^{-3}
0.01
0.02
0.05
0.1
$k\ (\mathrm{kms}^{-1})^{-1}$

Another problem is that the photoionization rate may fluctuate spatially:

$$\tau \propto n_{HI} = A\,\rho^{\beta},$$

$$A = 0.946\left(\frac{1+z}{4}\right)^{6}\left(\frac{\Omega_b h^2}{0.0125}\right)^{2}\left(\frac{T_0}{10^4\ \mathrm{K}}\right)^{-0.7}\left(\frac{\Gamma}{10^{-12}\ \mathrm{s}^{-1}}\right)^{-1}\left(\frac{H(z)}{100\ \mathrm{km\ s^{-1}\ Mpc^{-1}}}\right)^{-1}$$

$$\Gamma_{\mathrm{H\,I}} = \int_{\nu_{\mathrm{H\,I}}}^{\infty} d\nu\, \frac{4\pi J(\nu)}{h\nu}\, \sigma_{\mathrm{H\,I}}(\nu)$$

This will happen if the UVBG is generated by discrete sources, such as galaxies or QSOs.

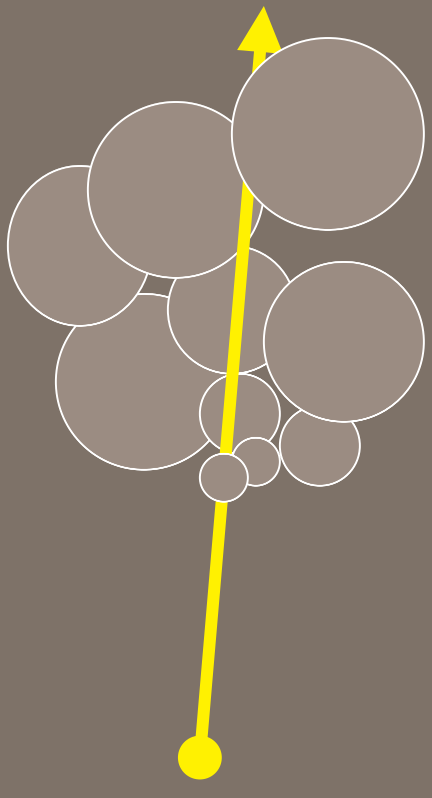
However, the mean free path of an ionizing photon is ~100 Mpc/h at z=3. This is much larger than our 33 Mpc/h hydro simulation volume.

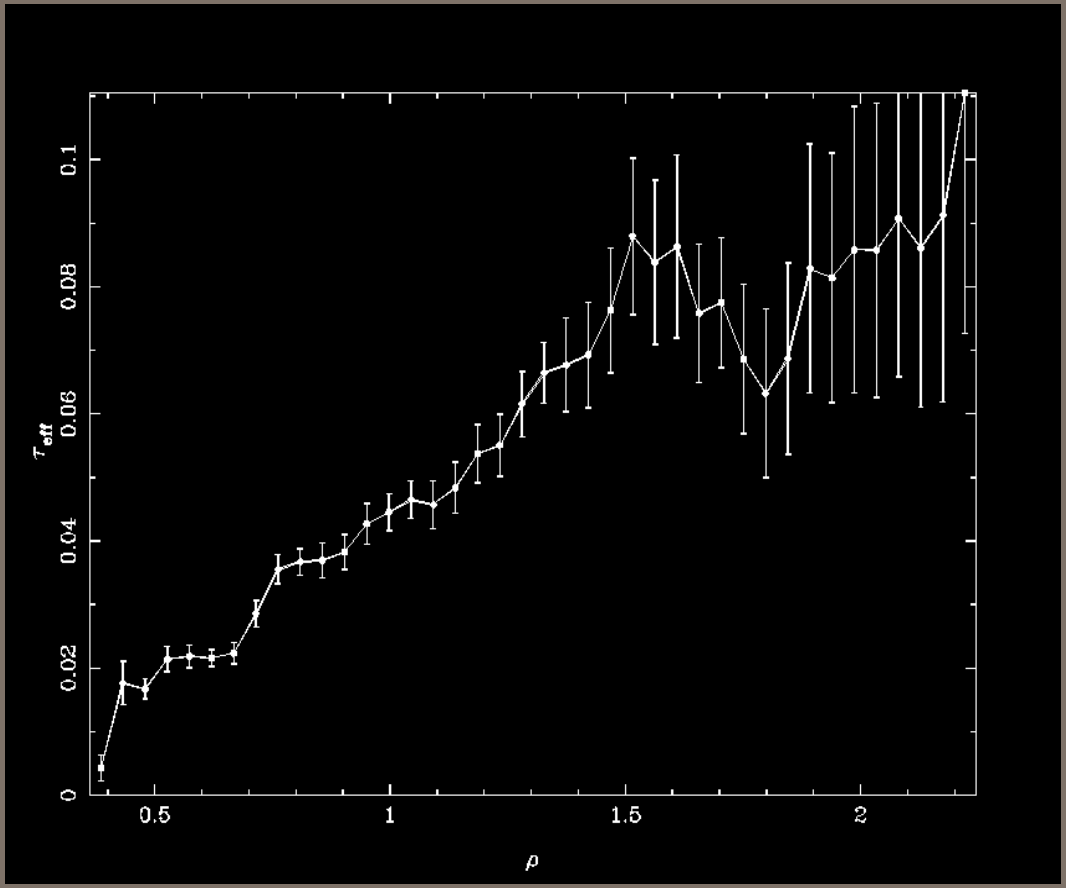
-we will investigate this effect by combining with a large 500 Mpc/h dark matter run.

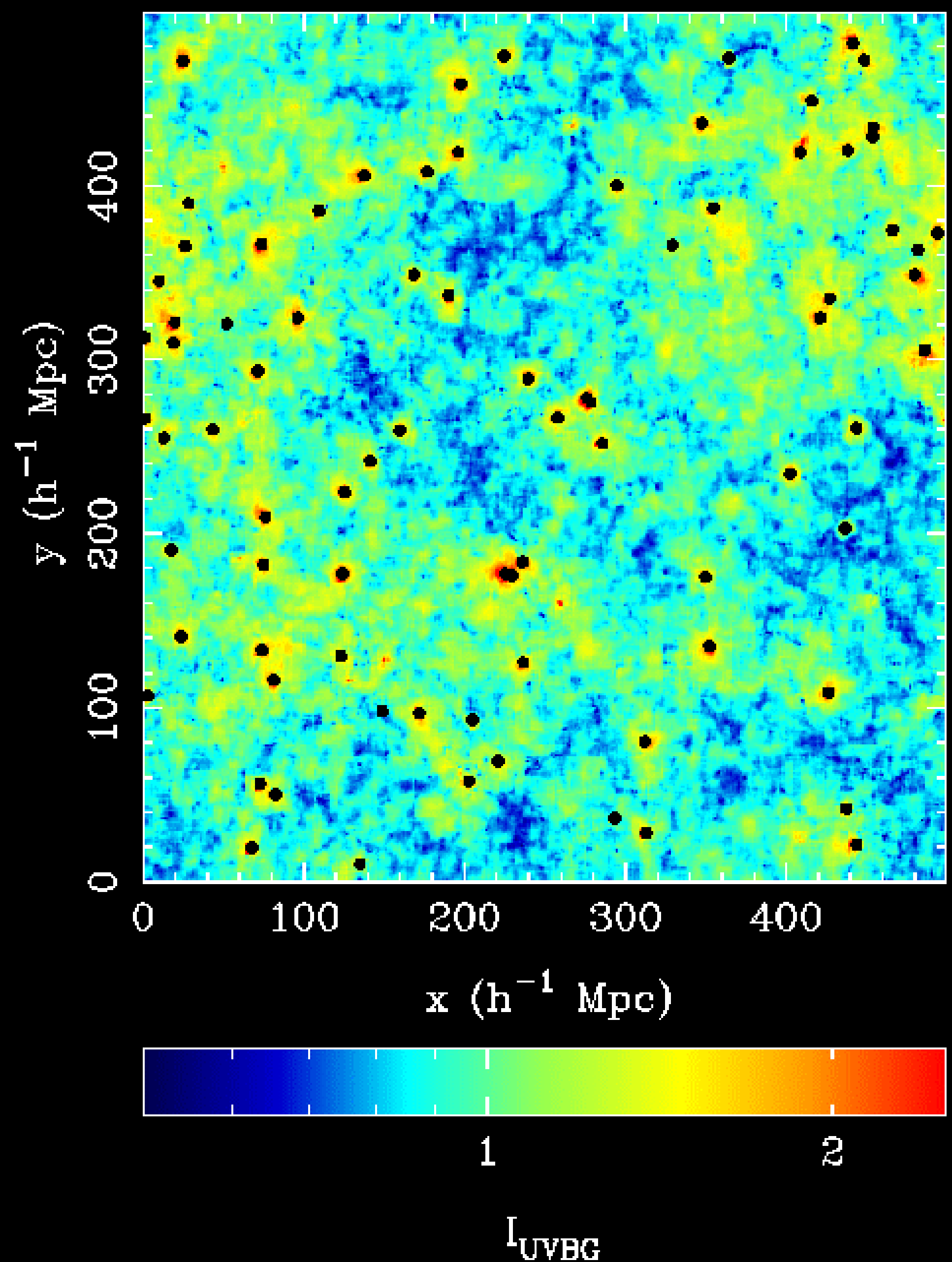
We raytrace photons through the density distribution of the simulation.

-quasar sources are taken be at the positions of density peaks

-quasar LF from Pei (1995)

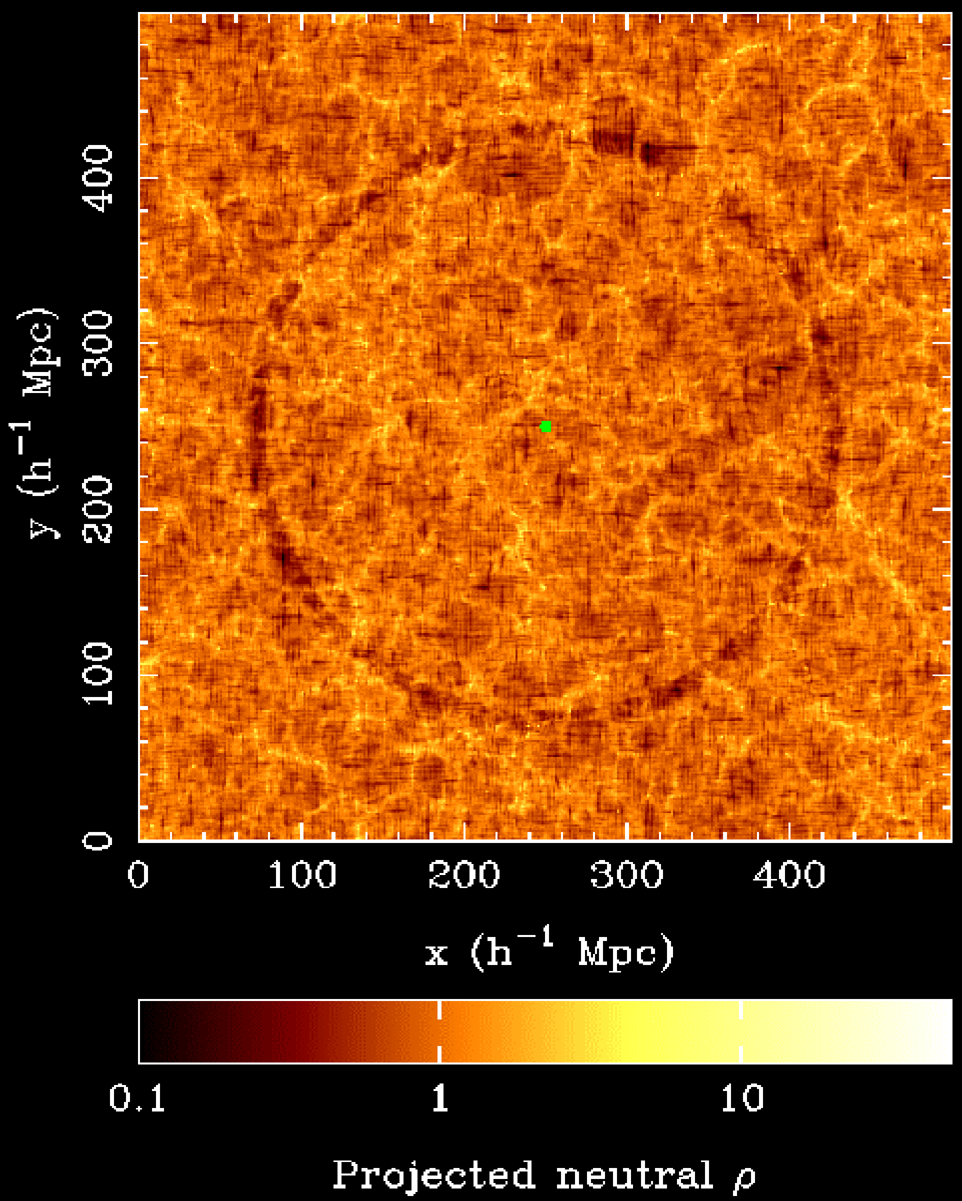




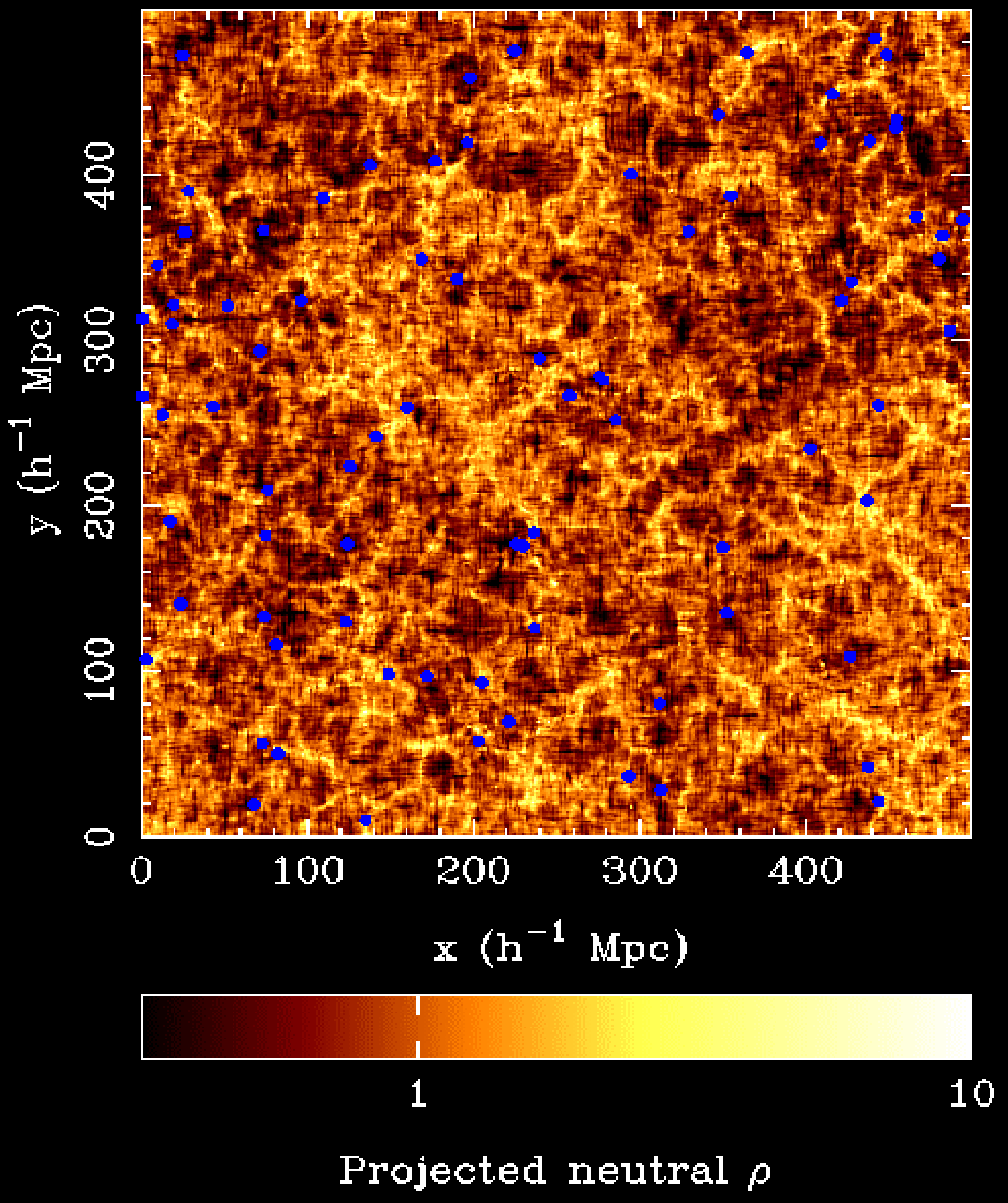


y (h^{-1} Mpc)
0
100
200
300
400
x (h^{-1} Mpc)
1
2
I_{UVBG}

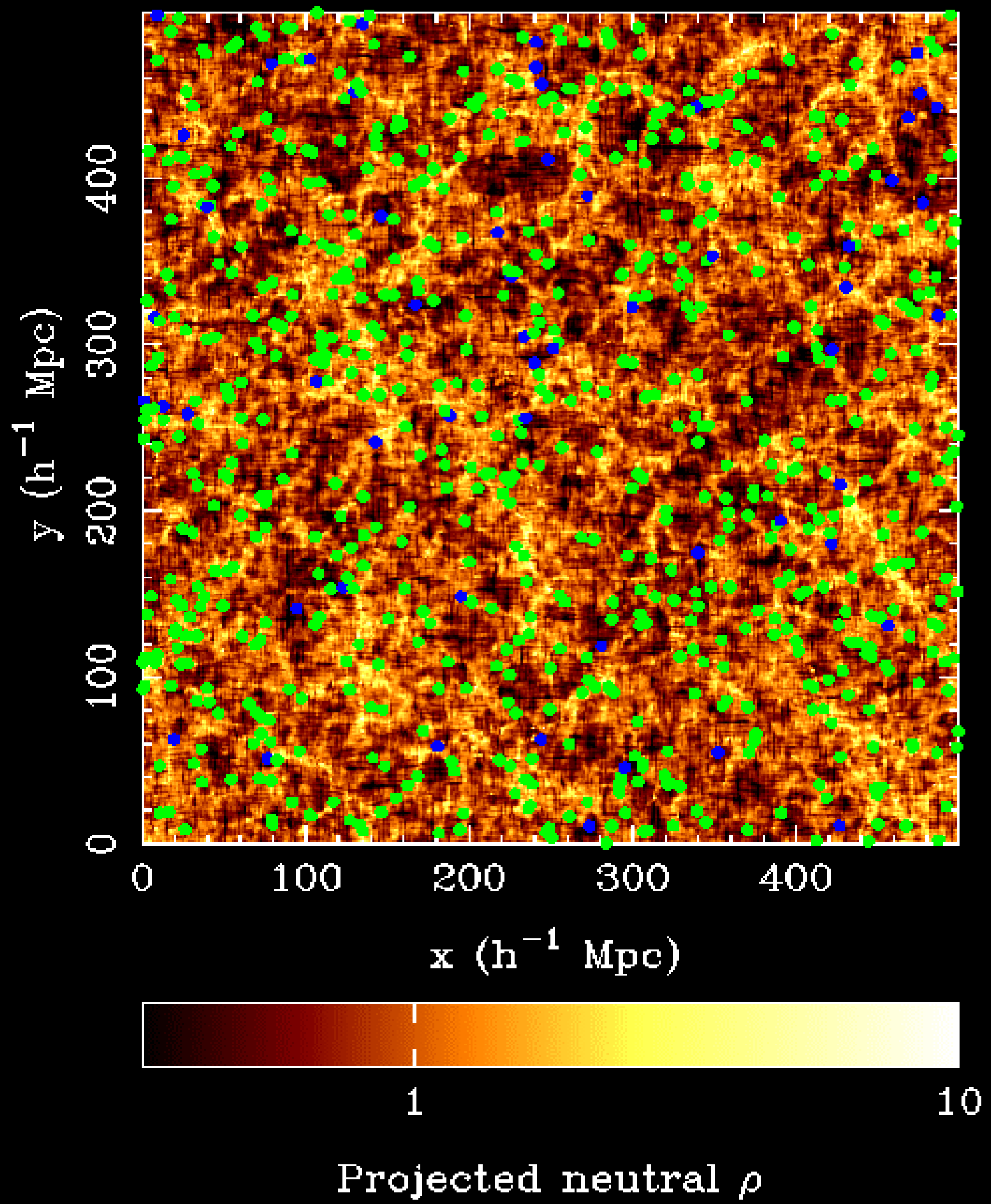
State of the Universe 100 million years after the turn on of a quasar with lifetime 10 million years.

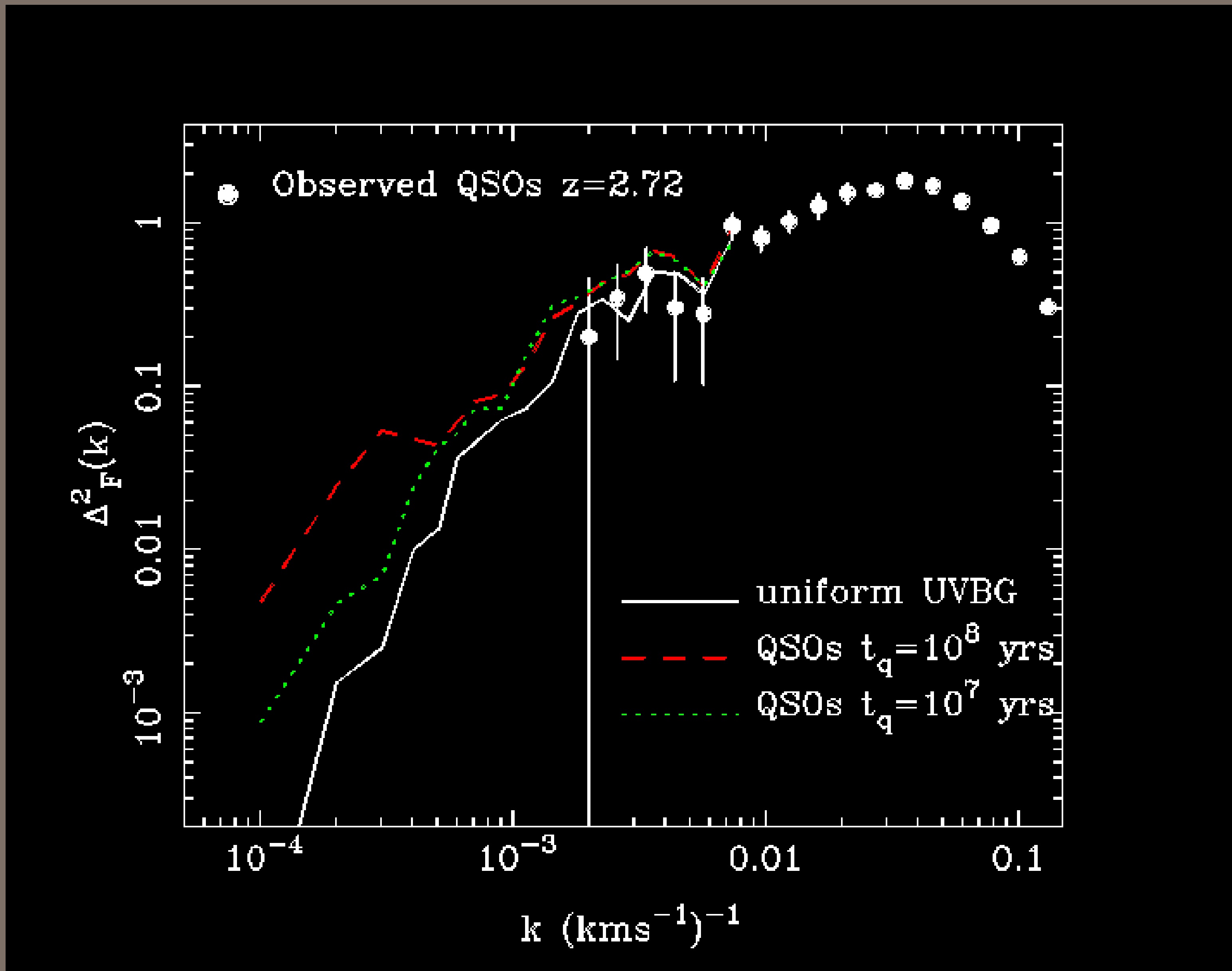


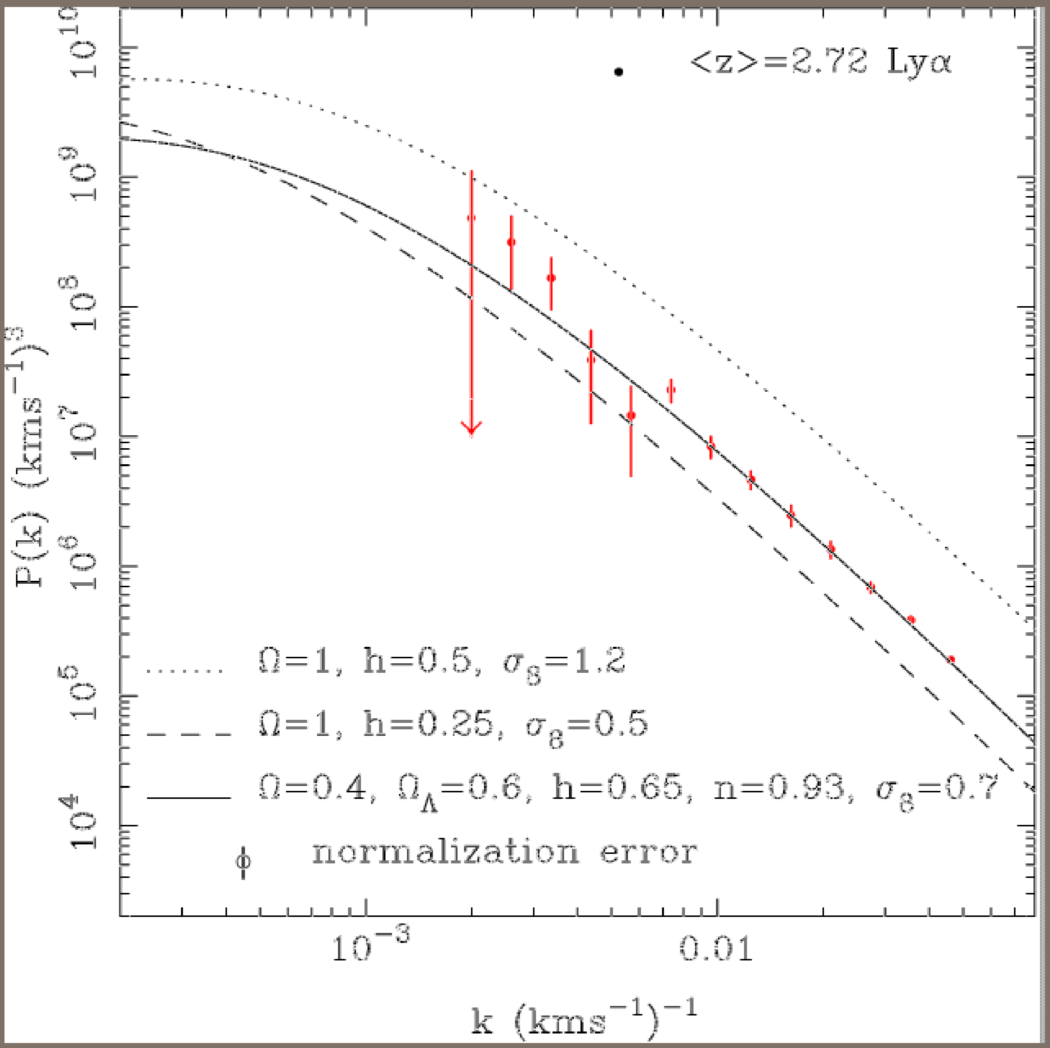
Quasars with lifetime 100 million years



Quasars with lifetime 10 million years
-green points are dead quasars




Observed QSOs z=2.72
uniform UVBG
QSOs $t_q=10^8$ yrs
QSOs $t_q=10^7$ yrs
$\Delta^2_F(k)$
1
0.1
0.01
10^{-3}
10^{-4}
10^{-3}
0.01
0.1
k $(\mathrm{kms}^{-1})^{-1}$



From Croft, Weinberg, Burles, Bolte, Hernquist, Katz, Kirkman and Tytler (2002), ApJ Dec 10th issue.

To determine relative suppression on small scales,
we need to constrain amplitude of matter fluctuations on large scales.

We also have the measurement in km/s at z=3. The relationship between this and lengths scales at z=0 depends on cosmology

Additional constraints used to meet both these objectives:

(a) cluster abundance constraint on σ_8 (95% range 0.7-1.13 for Ω_m=0.35)

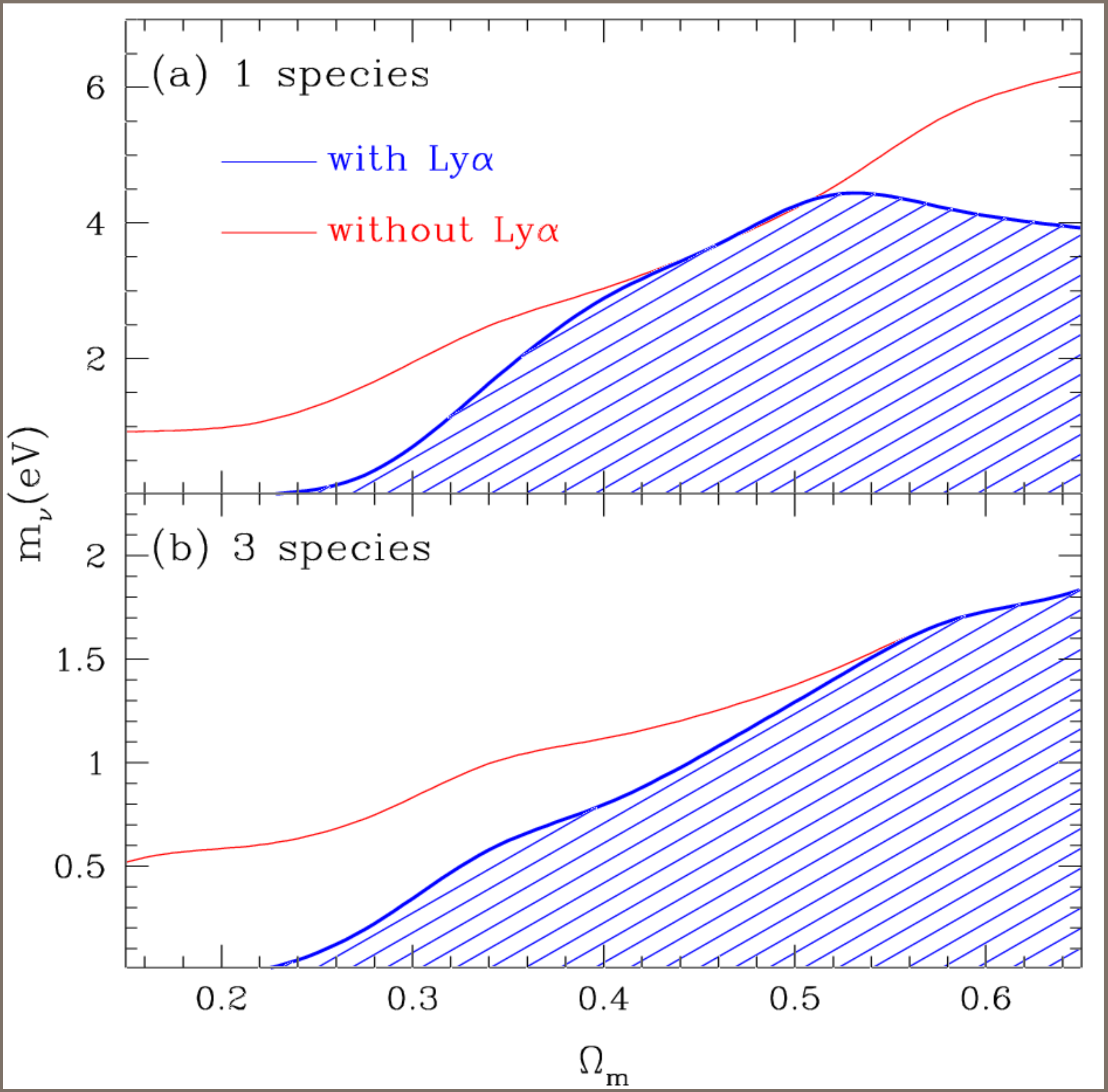
(b) COBE normalization on large scales.

(c) Universe is flat

(d) Shape of P(k) on scales 0.025 h/Mpc to 0.25 h/Mpc given by PD94

(e) Also we use BBN BT99 constraint on Ω_b and HST KP constraint on h
(but neither has any power to change results).

We rule out all regions of parameter space where on constraint is violated by 2 sigma (we do not multiply likelihoods together).



Conclusions

The Lyman-alpha forest is quite robust:

-galactic superwinds at z=3 can propagate into the underdense IGM but don't affect the majority of Lya forest clustering.

-UVBG fluctuations may cause the flux P(k) to vary by up to a factor of 10 on large scales, but not on the scales that have so far been used to constrain the neutrino mass.

The Lyman-alpha forest is a useful probe of power in the mass density field on small scales.

-combined with other constraints to tie down the large scale end, we find that $M_v < 4.5$ eV for all values of Ω_m.

-for $\Omega_m < 0.3$, we find $M_v < 0.7$ eV